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Coalition Warfare Program Tactile Situation Awareness System for Aviation Applications: Simulator Flight Test

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14. ABSTRACT
The Tactile Situational Awareness System (TSAS) is designed to provide hover feedback via the sense of touch, permitting helicopter pilots to maintain aircraft control within degraded visual environment (DVE). In Part 1 of our effort (reported in Lawson and Rupert, 2014), several improvements were made to the TSAS. In Part 2 of the effort (discussed in the present report), the improved TSAS was evaluated during simulated flight testing. The test evaluated the ability of the TSAS to improve a pilot's hover stability in a simulated DVE or brownout condition. The TSAS was integrated into a UH-60 simulator successfully and a trend towards smaller mean hover deviation was observed among 10 pilots while TSAS was in use. Further testing is recommended.

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degraded visual environment, brownout, hover, situation awareness, spatial orientation, tactile, TSAS

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Preface

This report describes a pilot evaluation of The Tactile Situation Awareness System (TSAS) during simulated flight. The objective was to evaluate the ability of TSAS to improve a pilot's hover stability in a simulated degraded visual environment (DVE or "brownout") condition. The Department of Defense (DoD) Coalition Warfare Program (CWP) funded the U.S. Army Aeromedical Research Laboratory (USAARL) to refine the Tactile Situation Awareness System (TSAS) and deliver it to aviation rotary-wing operators (Lawson and Rupert, 2014). The refined system was then tested by Chesapeake Technology International (CTI) and the test results provided to the Naval Aviation Center for Rotorcraft Advancement (NACRA) at the conclusion of CTI's SBIR Project Contract No.: N68335-09-C-0025. The findings are reiterated in this report with permission of NACRA and CTI.

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Introduction

The idea of employing tactile displays to maintain spatial orientation and situation awareness during flight was introduced at a 1989 Advisory Group for Aerospace Research & Development (AGARD) meeting in Copenhagen (Rupert, Mateczun, and Guedry, 1990). Subsequent flight testing in fixed-wing (Rupert, Guedry, and Reschke, 1994) and rotary-wing aircraft (Raj, Suri, Braithwaite, and Rupert, 1998) demonstrated that continuous, intuitive orientation information could be provided via tactile cueing.

The Tactile Situation Awareness System (TSAS) used for the evaluations described in this report is made up of a commercial processor (that determines if the aircraft is in a potentially dangerous flight regime and passes simple intuitive commands to a pilot via a lightweight vest), a cockpit control panel, a vest (garment containing vibrotactile stimulators called tactors that are positioned on the torso), and a seat cushion to provide altitude indications. This garment provides the aircraft operator (pilot/copilot) with flight control feedback intuitively through the sense of touch. During the system development aspect of this effort (Lawson and Rupert, 2014), key improvements were made to the TSAS garment, avionic interface, and software. The present report summarizes recent findings obtained during a simulated helicopter flight employing TSAS. The objective was to evaluate the ability of TSAS to improve a pilot's hover stability in a simulated degraded visual environment (DVE or "brownout") condition. TSAS was integrated into a UH-60 (Black Hawk) full-motion helicopter simulator located at Naval Air Station (NAS) Patuxent River, MD. Ten pilots evaluated TSAS during flight. Their findings are reported below.

TSAS test results

The test results were originally provided to the Naval Aviation Center for Rotorcraft Advancement (NACRA) by Chesapeake Technology International (CTI) at the conclusion of SBIR Project Contract No.: N68335-09-C-0025. The findings are presented below with permission of NACRA and CTI. Data Rights to information from this SBIR are covered via standard clauses that were assigned per the contract (U.S. Department of Defense, 1995).

Objective

To evaluate the ability of TSAS to improve a pilot's hover stability in a simulated DVE.

Methods

TSAS was integrated into the UH-60 simulator at the Manned Flight Simulator building located at NAS Patuxent River, MD. Ten operational pilots each evaluated TSAS during 1.5 hour sessions, each on 16 and 17 September of 2010. The ADS-33E-PRF standard (U.S. Army Aviation and Missile Command, 2000) was used as the basis for rating pilot maneuvers and performance. Navigation data from the simulation were forwarded to TSAS over User Datagram

Protocol (UDP) at 50 Hertz (Hz). The testing sequence was done in three stages completed by each pilot:

(1) Pre-brief and familiarization: To determine TSAS capabilities and expected effectiveness, the ten pilots were pre-briefed on the system and test procedures and then entered the UH-60 simulator with full motion activated. They were allowed time to familiarize themselves with the UH-60 simulator, the ADS-33 course installed in the simulated environment, and the sensations from TSAS. This familiarization period lasted approximately 10 minutes.

(2) Test events: For each hover test event, pilots were reset approximately 300 feet (ft) from the ADS-33 hover course. Each pilot then proceeded to the designated hover point as illustrated in figure 1. Each pilot was then asked to maintain position, using the “hover box” and traffic cones as visual cues to maintain position and altitude. Once comfortable with position and stability of hover, pilots notified the evaluation conductor to begin the test at which point a hover test scenario started. Afterwards, pilots completed a Cooper-Harper Handling Qualities Rating (HQR) form (shown in figure 2) in the cockpit prior to starting the next test event. Each pilot did multiple test scenarios that are described on pages 5 and 6 of this report.

(3) After the test scenarios were concluded, each pilot was debriefed by a NACRA representative and comments were collected during post-flight evaluation as shown in figure 3. The evaluation contains ratings of TSAS and comments on TSAS characteristics.

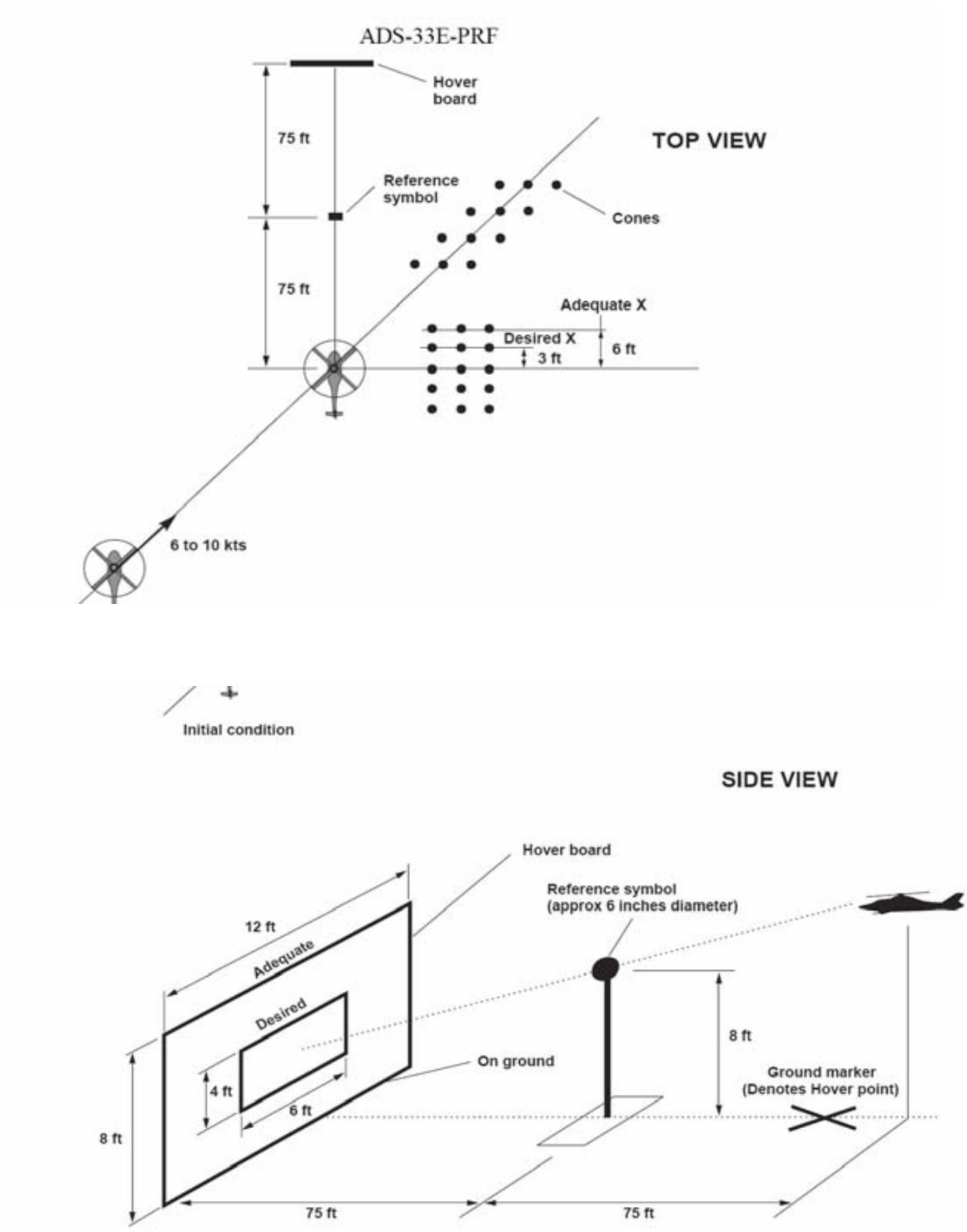


Figure 1. Representation of hover course.

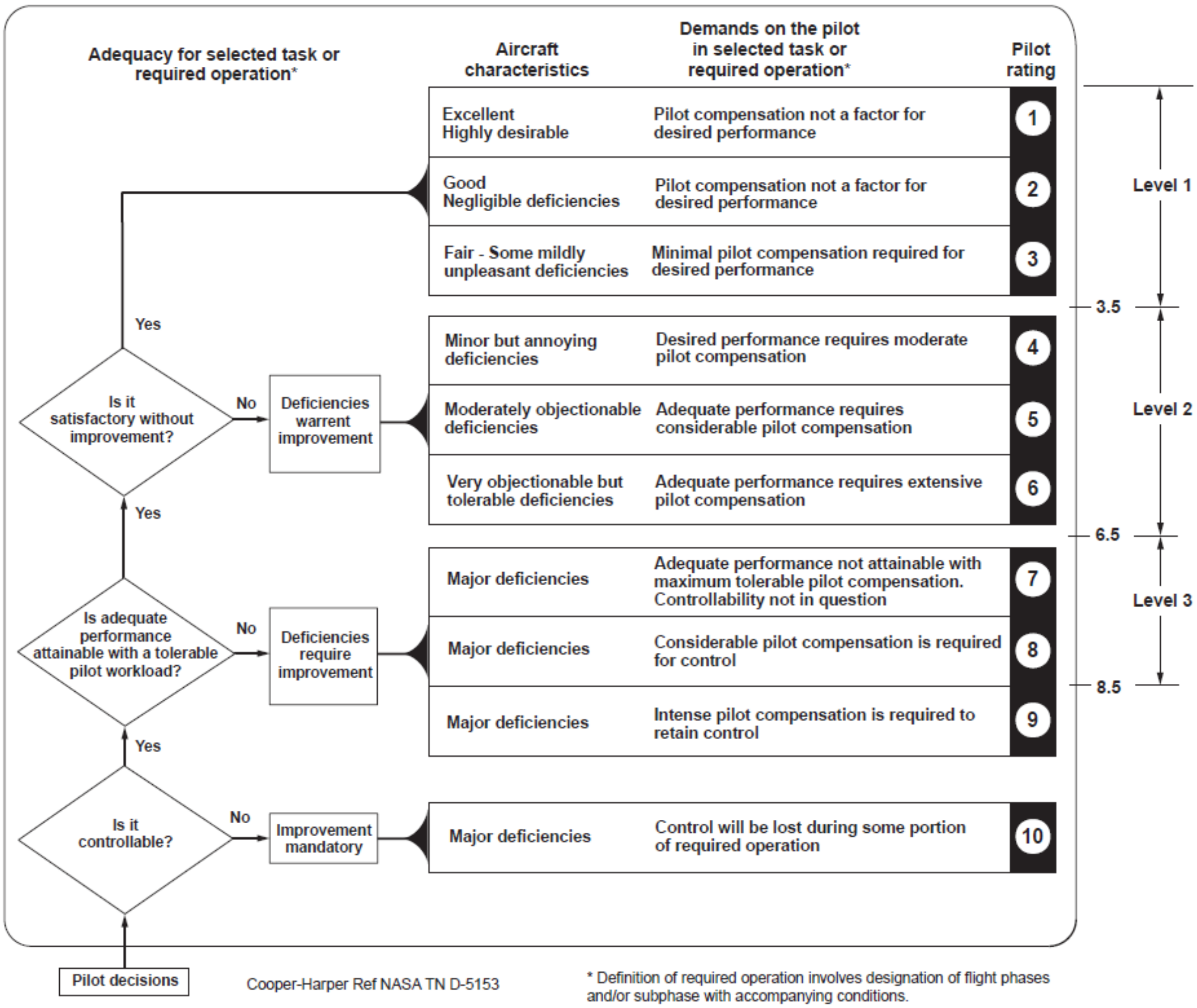
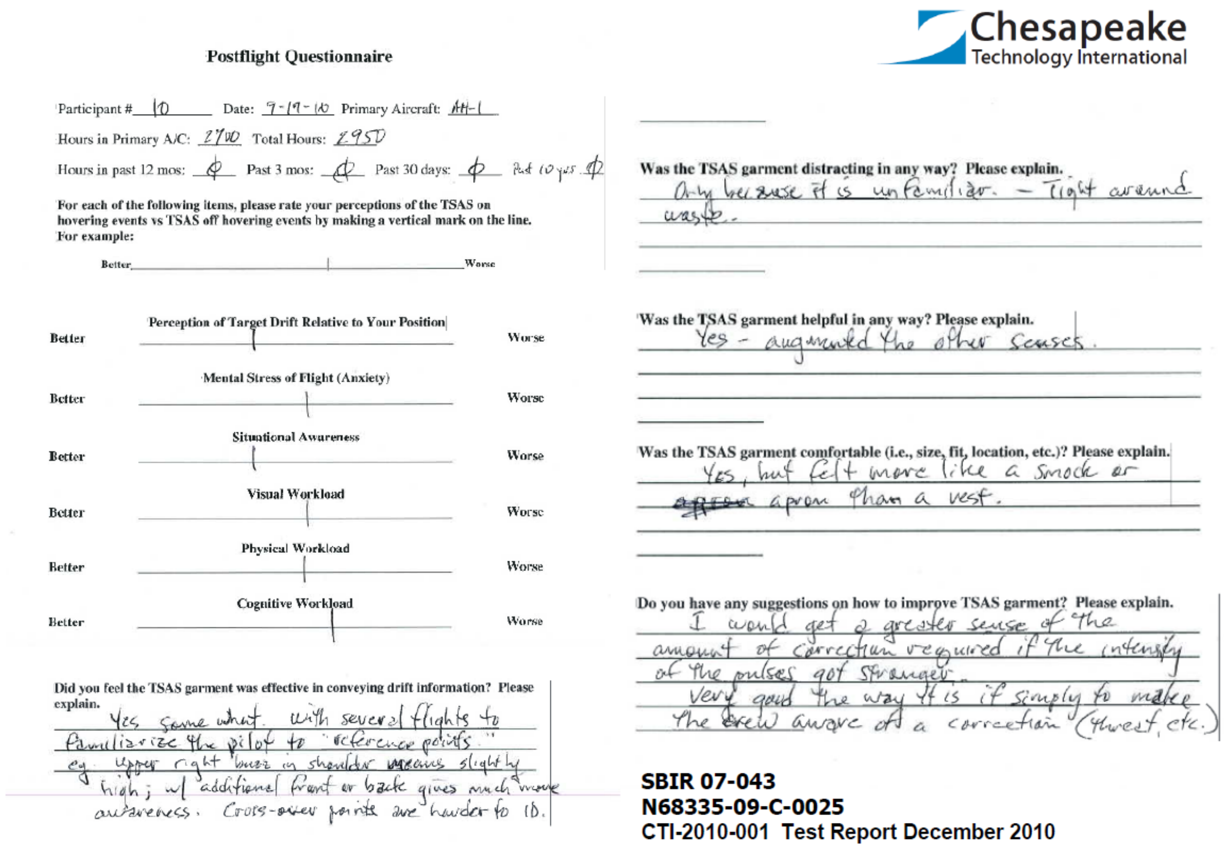


Figure 2. Handling Qualities Rating form.



Postflight Questionnaire

Chesapeake Technology International

Participant # 10 Date: 9-19-10 Primary Aircraft: AH-1

Hours in Primary A/C: 2700 Total Hours: 2950

Hours in past 12 mos: ϕ Past 3 mos: ϕ Past 30 days: ϕ Past 10 yrs ϕ

For each of the following items, please rate your perceptions of the TSAS on hovering events vs TSAS off hovering events by making a vertical mark on the line. For example:

Better Worse

Perception of Target Drift Relative to Your Position — Better / Worse

Mental Stress of Flight (Anxiety) — Better / Worse

Situational Awareness — Better / Worse

Visual Workload — Better / Worse

Physical Workload — Better / Worse

Cognitive Workload — Better / Worse

Did you feel the TSAS garment was effective in conveying drift information? Please explain.
Yes some what. with several flights to familiarize the pilot to "reference points." eg. upper right buzz in shoulder means slightly high; w/ additional front or back gives much more awareness. Cross-over points are harder to ID.

Was the TSAS garment distracting in any way? Please explain.
Only because it is unfamiliar. – Tight around waste.

Was the TSAS garment helpful in any way? Please explain.
Yes – augmented the other senses.

Was the TSAS garment comfortable (i.e., size, fit, location, etc.)? Please explain.
Yes, but felt more like a smock or ~~apron~~ apron than a vest.

Do you have any suggestions on how to improve TSAS garment? Please explain.
I would get a greater sense of the amount of correction required if the intensity of the pulses got stronger. Very good the way it is if simply to make the crew aware of a correction (thrust, etc.)

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N68335-09-C-0025
CTI-2010-001 Test Report December 2010

Figure 3. Post-flight questionnaire.

Hover test scenarios

The intent of the test was to compare pilot responses with and without TSAS engaged, and with and without a DVE. There were four hover scenarios planned and performed by each pilot.

The four test scenarios were presented in the following order to each pilot:

(1) Clear visual environment (CVE), no TSAS: Each pilot performed a 60 second (s) baseline hover test in CVE.

(2) CVE, with TSAS: Each pilot performed a 60 s hover test in CVE with TSAS engaged by evaluation conductor.

(3) DVE, no TSAS: Each pilot performed a 60 s hover test in DVE, with DVE incremented at the start of the test to 50, 70, 90, 93, 95, 97, and 99 percent every 10 s.

(4) DVE, with TSAS: Each pilot performed a 60 s hover test in DVE, TSAS engaged, with DVE incremented at the start of the test to 50, 70, 90, 93, 95, 97, and 99 percent every 10 s. If

time was available, the pilot was asked to perform a free flight around the airfield for a few minutes, and then asked to repeat DVE tests for additional data gathering.

Some pilots performed multiple iterations of singular test scenarios during the testing session. This was done to provide as much information for data analysis as time permitted.
Each test scenario was standardized so that each pilot received the same DVE conditions during a 60 s run.

TSAS algorithms

TSAS utilizes an onboard configuration file which is processed during System Power Up/Initialization to determine configuration settings. The configuration file is in Extensible Markup Language (XML) format and is human readable and editable. The algorithm variable settings used for these test scenarios were recommended by Dr. Angus Rupert of the USAARL. The algorithm is described in "Configuration Parameters for the Tactile Situation Awareness System (TSAS)" dated July 2010 (Configuration Parameters, 2010).

Findings

The plots shown below are summary indications of the data collected for all 10 pilots. Flight analysis was accomplished by determining the intended hover position of the pilot at the beginning of the test. After saving this position, the magnitude of deviations in latitude, longitude, and altitude were recorded for each flight. These data were then averaged to determine the effectiveness of TSAS for all pilots in the scenarios detailed above.

Pilot hover deviation in a CVE

Figure 4 shows hover deviations that the pilots exhibited when in CVE with and without TSAS. At the time of the maximum deviation from hover, TSAS enabled approximately a 70 percent decrease in aircraft movement. The chart indicates the 60 s timeline for the test sequence for the X-axis and indicates hover deviation in feet for the Y-axis.

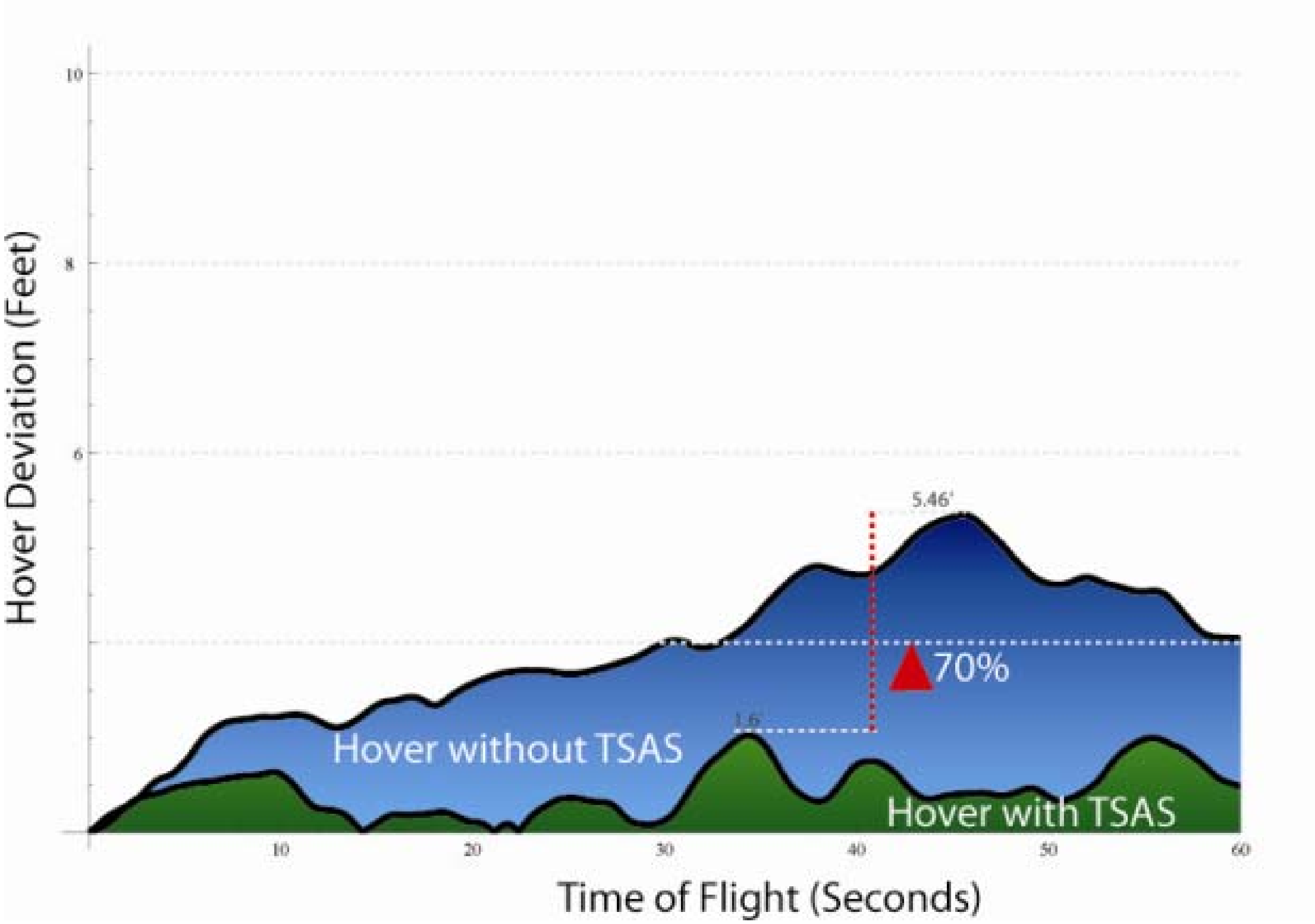

Figure 4. Average hover deviation of all CVE flights.

Pilot hover deviation in a DVE

Figure 5 shows hover deviations that the pilots exhibited when in DVE conditions with and without TSAS. The brownout conditions were introduced into the pilot's field of view on a timed sequence. Observations in the cockpit indicated that around 97 percent, obscuration grew severe enough to dramatically affect hover performance. This was approximately when the pilot lost visual references and the point at which most pilots responded that they were uncomfortable with the hover conditions. At or beyond 97 percent obscuration, with TSAS enabled, the pilots were able to maintain a stable hover position (defined as a four foot deviation limit), which equates to approximately a 73 percent average decrease in movement over the 60 s of testing.

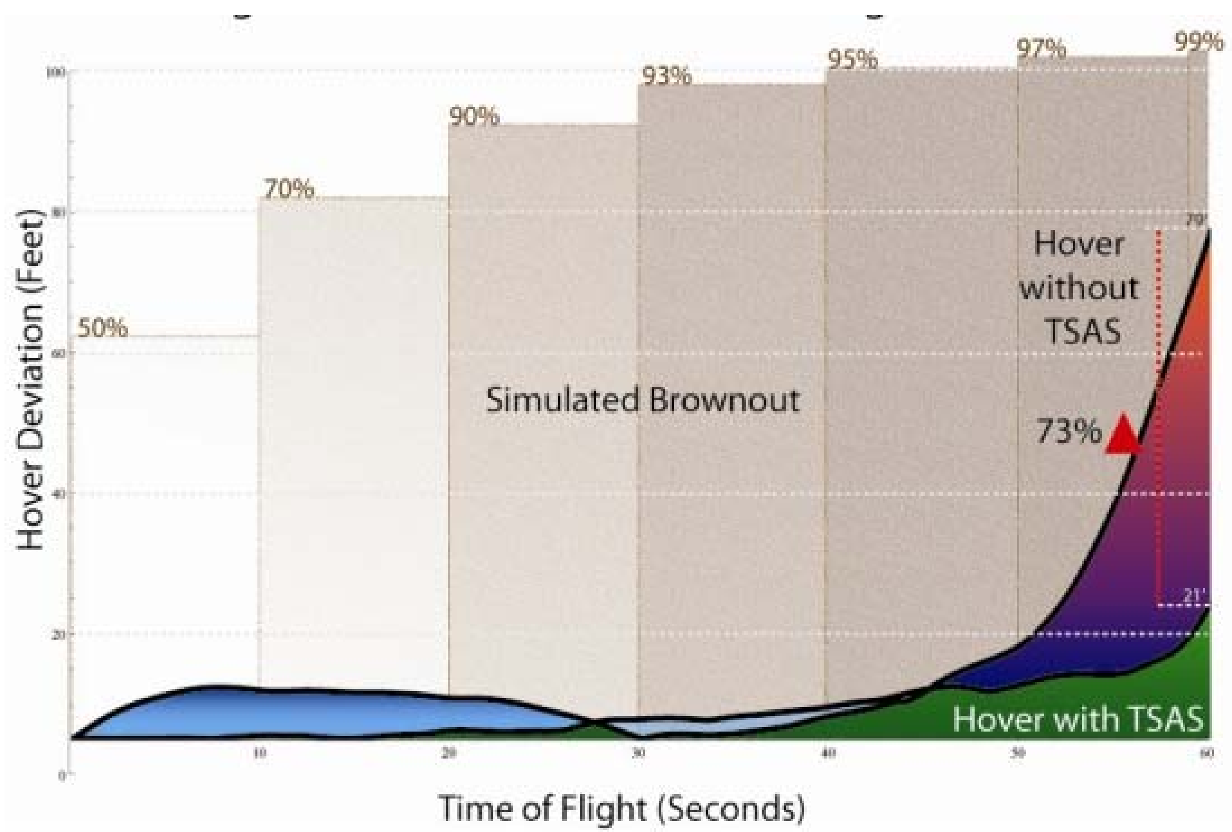

Figure 5. Average hover deviation of all DVE flights.

Table 1 presents cumulative descriptive statistical information for all tests per the four test scenarios used: CVE (no TSAS), CVE with TSAS, DVE (no TSAS) and DVE with TSAS. Of note are three statistics:

a. The mean distance traveled from a stable hover position during the entire 60 s test scenario for each test pilot. Note that in either the CVE or the DVE conditions, the pilots showed marked improvement when TSAS was engaged.

b. The minimum distance traveled from a stable hover position during the 60 s scenario (i.e., minimum for each pilot, averaged across all pilots).

c. The maximum distance traveled from a stable hover position during the 60 s scenario (averaged across the pilots). Note the reduction in deviation for the DVE condition with and without TSAS engaged.

Overall, the descriptive statistics presented in table 1 show that mean hover deviation in the UH-60 Simulator is smaller during CVE and DVE when TSAS is present (versus when TSAS is not assisting). A limitation to this conclusion is that it has not been supported by conducting inferential statistics. While the raw data were not available at the time of preparation of this technical report, an estimate of significance was attempted using the mean and range information in Table 1. We applied the range rule to estimate standard deviation (as the range divided by four), then carried out an independent t-test on the available means. This estimate detected a significantly reduced hover deviation during CVE flying with TSAS (versus without TSAS, $t = 5.19$, $p = 0.0001$), but not during DVE flight ($t = 1.1$, $p = 0.14$), probably because of the wide range of values observed in the DVE (without TSAS) group. This should be considered a rough estimate, however, since it was applied to a small sample without precise information about standard deviations, normality, or homogeneity of variance. Also, it should be noted that while a dependent t-test is not possible without the original data, such a test would have been justified with these data and may have shown a statistically significant reduction in hover deviation under both CVE and DVE.

A possible reason for the failure to detect an effect under DVE is an insufficient sample of pilots. An estimate of statistical power was conducted, which confirmed that the study was under-powered to detect an effect at $n = 10$ (i.e., $n = 30$ would be desirable for 0.80 power). This is common problem for resource-limited operational studies requiring trained pilots. It would be beneficial to gather additional data under this flight testing scenario in future.

Table 1.
Pilot ADS33 hover deviation.

	CVE	***CVE w/ TSAS***	***DVE***	***DVE w/ TSAS***
Mean (ft)	3.1538	0.7077	11.2723	4.1170
Mean Minimum (ft)	0	0	0	0
Mean Maximum (ft)	5.4698	1.6695	79.3690	20.2442

Pilot ratings

After each test event, the pilot was asked to complete the HQR form in accordance with ADS-33E-PRF standard (U.S. Army Aviation and Missile Command, 2000). A scale ranging from 1 (excellent) to 10 (major deficiency) was used. The HQR revealed that in a brownout condition, there was a trend towards improvement in pilot rating of these preliminary test configuration settings.[1] Note: The lower the rating, the better the indication that the pilot could handle the aircraft. Figure 6 and table 2 summarize the HQR data.

[1] The same caveats concerning lack of inferential statistics apply to these ratings as above for hover performance values; however, estimating t-test results based on HQR ratings would less appropriate.

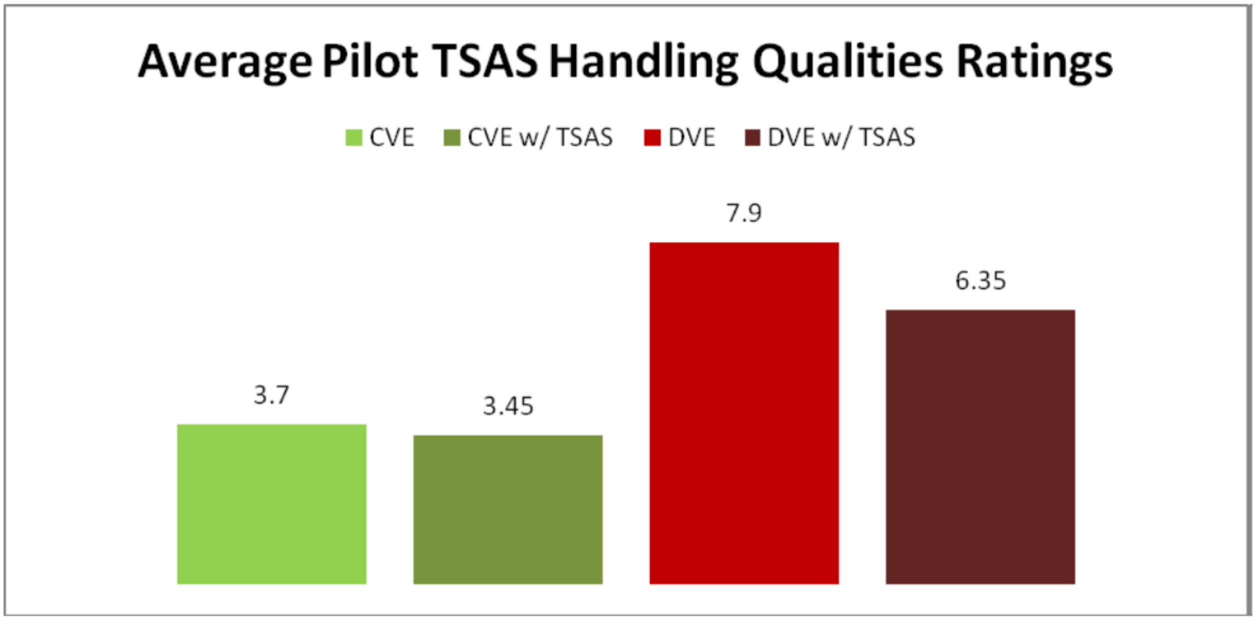

Figure 6. Average HQR.

Table 2.
HQR ratings.

	CVE	CVE w/ TSAS	DVE	DVE w/ TSAS
Mean	3.7	3.45	7.90	6.35
Mean Minimum	3	2	5	4
Mean Maximum	5	4	9	9

For this study, there were no pilot distractions (e.g., emergencies, radio traffic, wind, hostile fire, cockpit distractions) introduced into the test scenario. In laboratory conditions during CVE, analysis of pilot flight characteristics indicates an average hover deviation of 5.46 feet occurs during 60 s of hover in any axis without TSAS engaged and 1.6 feet with TSAS engaged. While use of TSAS results in a substantial improvement (70 percent to hover deviation), the actual distance improved appears to be only 3.86 feet. This small absolute difference is to be expected under clear visual flying conditions.

To compare CVE and DVE, two metrics are selected: duration and amplitude of hover deviation. The metrics are assessed during the entire 60 s test with a timed DVE setting ranging from 0 to 99.9 percent DVE. These two metrics address the following questions: (1) How long can a pilot maintain less than 8 ft (summed in all axes) of distance from the point of hover entry into DVE conditions with and without TSAS engaged? (2) What is the average hover deviation (summed in all axes) in DVE conditions with and without TSAS engaged? Table 3 summarizes the answers to these questions, and suggests that TSAS is very helpful in a DVE. As brownout conditions worsen, an increase in hover deviation is observed and TSAS reduces a pilot's hover error. Results indicate that TSAS has the potential to extend a pilot's ability to hover under DVE and reduce a pilot's overall excursion from a hover zone.

Table 3.
Hover deviation during DVE.

	Without TSAS	*With TSAS*		*Improvement with TSAS*
Duration Hover Deviation is Maintained within +/- 8 ft	10 s	49 s		79 %
Average Magnitude of Hover Deviation	11.30 ft	4.11 ft		63 %

Conclusion

This user evaluation assessed the ability of TSAS to improve a pilot's hover stability in a simulated DVE. Ten pilots evaluated TSAS during simulated flight conditions. The flight test events consisted of four hover scenarios that each pilot performed: CVE with TSAS, CVE without TSAS, DVE with TSAS and DVE without TSAS. The magnitude of deviation in latitude, longitude and altitude were recorded from each flight. The descriptive data showed a trend for mean hover deviation (from the desired hover point) to be smaller when TSAS was present, although large variability in hover performance was observed in this small sample of pilots. Further pilot testing is recommended.

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Acronyms

AGARD – Advisory Group for Aerospace Research & Development
CTI – Chesapeake Technology International
CWP – Coalition Warfare Program
CVE – Clear Visual Environment
DoD – Department of Defense
DVE – Degraded Visual Environment
HQR – Handling Qualities Rating
NACRA – Naval Aviation Center for Rotorcraft Advancement
NAS – Naval Air Station
ORISE – Oak Ridge Institute for Science and Education
SBIR– Small Business Innovation Research
TPA – Test Project Agreement
TSAS – Tactile Situation Awareness System
UDP – User Datagram Protocol
XML – Extensible Markup Language

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